

CHAPTER 3

DESIGN AND SELECTION OF UNINTERRUPTIBLE POWER SUPPLY (UPS)

3-1. Selecting an UPS

The process for selecting an UPS consists of eight steps. These steps are: determining the need for an UPS, determining the purpose(s) of the UPS, determining the power requirements, selecting the type of UPS, determining if the safety of the selected UPS is acceptable, determining if the availability of the selected UPS is acceptable, determining if the selected UPS is maintainable, and determining if the selected UPS is affordable. The last four steps may require repeating if the UPS does not meet all of the requirements. This process does not and cannot provide a “cookbook solution.” Each facility has unique requirements for emergency and standby power. These requirements include the reliability of the prime power source, the nature of the work done, local and state regulations governing emergency power, etc. The process does not give a single solution that is applicable to all cases. It is hoped, however, that it provides the framework for selecting an UPS for any facility. Figure 3-1 illustrates this process. To help illustrate how the selection procedure can be used, an example is provided in appendix B. This example is completely fictitious and should not be considered as “the” model for how the selection process would be used in every case. It does, however, illustrate the many factors that go into the decision process and the need for a good staff to assist the facility manager in making the UPS selection.

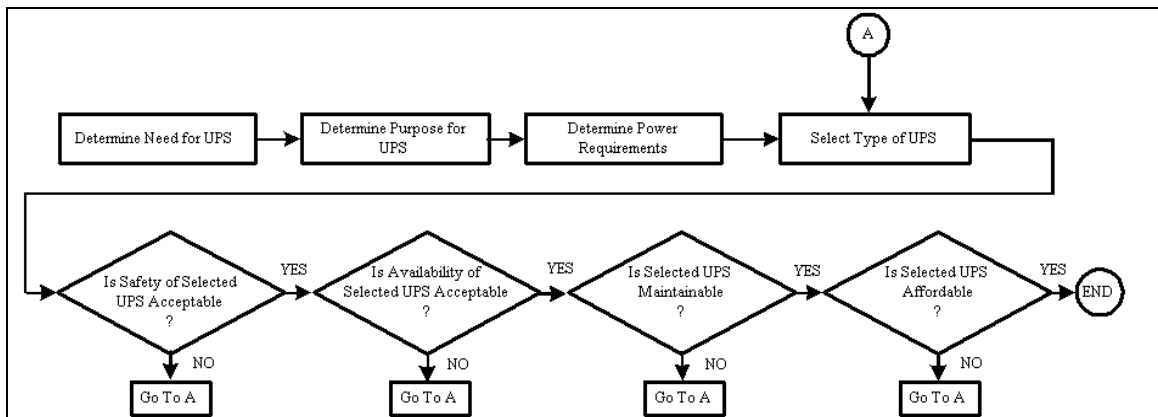


Figure 3-1. Determine the general need for an UPS

a. Determine the general need for an UPS. The assessment process for determining the need for a facility UPS is shown in figure 3-2. Determining the need for an UPS is mainly a matter of evaluating the way in which a facility is used, as well as knowing whether local, state, or federal laws mandate the incorporation of an UPS. The number of regulations mandating an alternate power source to ensure safety of personnel and to prevent pollution of the environment continues to increase. Consequently, enforcement agencies should be consulted to determine if an UPS is mandated. They should also be consulted during design and installation to make sure that the UPS is designed and installed in accordance with current applicable regulations.

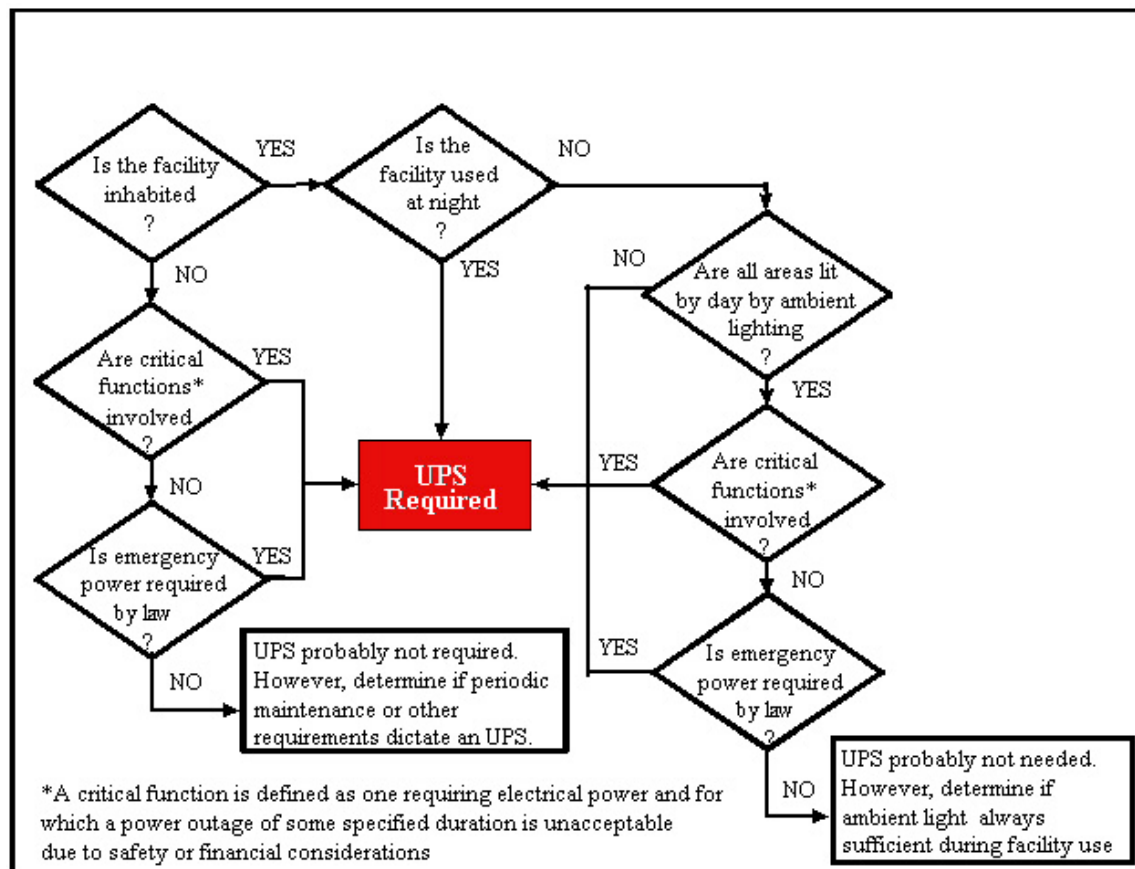


Figure 3-2. Determine the facility need for an UPS

b. Determine the purpose of the UPS. An UPS may be needed for a variety of purposes. These include emergency lighting for evacuation, emergency perimeter lighting for security, shut down or continued operation of manufacturing equipment or computer operations, continued operation of life support or critical medical equipment, continued operation of communications, and safe operation of equipment during sags and brownouts. Some facilities need an UPS for more than one purpose. In any case, the purpose(s) must be known before proceeding because it determines many factors that will drive the amount of power required and the type of UPS that will be needed. These factors are the acceptable delay between loss of primary power and availability of UPS power, the length of time that emergency or backup power is required, and the criticality of the load that the UPS must bear. Applications such as hospital life support and safety, aircraft tracking and landing, and certain production process controls and data processing cannot tolerate any loss of power, no matter how short the period of time, without loss of life or revenue. Other applications like refrigeration, heating, and cooling may tolerate loss of power for several minutes (or longer) without any adverse effects. For data processing equipment, it may be necessary to maintain power until the equipment can be shut down in an orderly manner. This process may take only a few minutes. Alternatively, life support, safety, communications and security equipment, and other applications may require continuous power until primary power is restored. Restoration of primary power could take hours or even days. A survey of commercial power outages may be necessary to determine this information. If commercial power outages are historically infrequent and last only a few minutes or hours, it may not make economical sense to install an UPS capable of supplying power for several days. Table 3-1 lists some general criteria

Power Needed For	Purpose	Maximum Tolerable Power Failure Duration	Recommended Minimum Auxiliary Supply Time	Type of Auxiliary Power		Justification for UPS
				Emergency	Standby	
Lighting	Evacuate Personnel	Up to 10s, preferably not more than 3s	2h	X		Prevent panic, injury, loss of life. Comply with building codes and local, state, and federal laws. Lower insurance rates. Prevent property damage. Lessen losses due to legal suits.
	Illuminate perimeter & for security	10 s	10-12 h during all dark hours	X	X	Lower losses from theft and property damage. Lower insurance rates. Prevent injury.
	Provide warning	From 10 s up to 2 or 3 min	Until prime power restored	X		Prevent or reduce property loss. Comply with building codes and local, state, and federal laws. Prevent injury and loss of life.
	Restore normal power system	1 s to indefinite depending on available light	Until repairs completed and power restored	X	X	Reduce risk of extended power and light outage due to a longer repair time.
	Provide general lighting	Indefinite; depends on analysis and evaluation	Indefinite; depends on analysis and evaluation		X	Prevent loss of sales. Reduce production losses Lower risk of theft. Lower insurance rates.
	Provide power to hospitals and medical areas	Up to 10s (NFPA 99-1996, ANSI/NFPA 101-1994); allow 10s for alternate power source to start and transfer power.	Until prime power restored	X	X	Facilitate continuous patient care by surgeons, medical doctors, nurses, and aids. Comply with all codes, standards, and laws. Prevent injury or loss of life. Lessen losses due to legal suits.
	Facilitate orderly shut-down	0.1 s to 1 h	10 min to several hours	X		Prevent injury, loss of life, and property loss by a more orderly and rapid shutdown of critical systems. Lower risk of theft. Lower insurance rates.
Startup Power	Startup power for boilers	3s	Until prime power restored	X	X	Restore production. Prevent property damage due to freezing. Provide required electric power .
Startup Power (continued)	Startup power for air compressors	1 min	Until prime power restored		X	Restore production. Power instrumentation.
Transportation	Power for elevators	15s to 1 min	1 h (Until prime power restored)		X	Safeguard personnel. Evacuate building. Continue normal activity.
	Power for material handling	15s to 1 min	1 h (Until prime power restored)		X	Complete production run. Permit orderly shutdown. Continue normal activity.
	Power for escalators	15s to no requirement for power	Zero to until prime power restored		X	Evacuate building. Continue normal activity.
Signal Circuits	Power for alarms and annunciators	1-10s	Until prime power restored	X	X	Prevent loss from theft, arson, or riot. Maintain security systems. Comply with codes, standards, and laws. Lower insurance rates. Alert operators to critical out-of-tolerance temperature, pressure, water level, and other hazardous or dangerous conditions.
	Land-based aircraft, railroad, and ship warning systems	1s to 1 min	Until prime power restored	X	X	Comply with local, state, and federal codes, standards, and laws. Prevent personnel injury. Prevent property and economic loss.
Mechanical Utility Systems	Water (cooling and general use)	15s	½h (Until prime power restored)		X	Continue production. Prevent damage to equipment. Provide fire protection.
	Provide water (drinking & sanitary)	1 min to no requirement	Indefinite until evaluated		X	Provide customer service. Maintain personnel performance.
	Provide boiler power	0.1s	1 h (Until prime power restored)	X	X	Prevent loss of electric generation and steam. Maintain production. Prevent damage to equipment.
	Power pumps for water, sanitation, and production fluids	10s to no requirement	Indefinite until evaluated		X	Prevent flooding. Maintain cooling facilities. Provide sanitation.. Continue production. Maintain boiler operation.

Table 3-1. General criteria for determining the purposes of an UPS

Table 3-1. General criteria for determining the purpose of an UPS (continued)

Power Needed For	Purpose	Maximum Tolerable Power Failure Duration	Recommended Minimum Auxiliary Supply Time	Type of Auxiliary Power		Justification for UPS
				Emergency	Standby	
Mechanical Utility Systems (continued)	Power fans & blowers for ventilation & heating	0.1s to until prime power restored	Indefinite until evaluated	X	X	Maintain boiler operation. Provide venting and purging of gas-fired units. . Maintain cooling and heating functions for buildings and production.
	Heating	5 min	Until prime power restored		X	Prevent loss of sales and profit. Prevent spoilage of in-process preparation.
	Sustain process	5 min	Indefinite until evaluated; normally for time for orderly shutdown, or until prime power restored		X	Prevent in-process production damage. Prevent property damage. Continue production. Prevent payment to workers during no production. Lower insurance rates
Refrigeration	Power special equipment or devices having critical warm-up (cryogenics)	5 min	Until prime power restored		X	Prevent equipment or product damage.
	Power critical depositories (e.g., blood bank)	5 min (10s per NFPA 99-1996)	Until prime power restored		X	Prevent loss of stored material.
	Power non-critical depositories (e.g., meat, produce)	2h	Indefinite until evaluated		X	Prevent loss of stored material . Lower insurance rates.
Production	Power critical process	1 min	Until prime power restored or until orderly shutdown		X	Prevent product and equipment damage. Continue normal production. Reduce payment to workers on guaranteed wages during nonproductive period. Lower insurance rates. Prevent prolonged shutdown due to non-orderly shutdown
	Process control power	Up to 1 min	Until prime power restored	X	X	Prevent loss of machine and process computer control program. Maintain production. Prevent safety hazards from developing. Prevent out-of-tolerance products.
Space Conditioning	Control critical temperatures	10s	1 min or until prime power restored	X	X	Prevent personnel hazards, product or property damage. Lower insurance rates. Continue normal activities. Prevent loss of computer function.
	Control critical pressures	1 min	1 min or until prime power restored	X	X	Prevent personnel hazards, product or property damage. Continue normal activities. Lower insurance rates. Comply with local, state, and federal codes, standards, and laws.
	Control critical humidity	1 min	Until prime power restored		X	Prevent loss of computer functions. Maintain normal operations and tests. Prevent hazards.
	Control static charge	10s or less	Until prime power restored	X	X	Prevent static electric charge and associated hazards. Continue normal production.
	Control building heating and cooling	30 min	Until prime power restored		X	Prevent loss due to freezing Maintenance of personnel efficiency. Continue normal activities.
	Ventilate for toxic fumes	15s	Until prime power restored or orderly shut-down	X	X	Reduce health hazards. Comply with local, state, and federal codes, standards, and laws. Reduce pollution
	Ventilate for explosive atmosphere	10s	Until prime power restored or orderly shutdown	X	X	Reduce explosion hazard. Prevent property damage. Lower insurance rates. Comply with local, state, and federal codes, standards, and laws. Lower hazard of fire. Reduce hazards to personnel
	General ventilation	1 min	Until prime power restored		X	Maintain personnel efficiency. Provide make-up air in building.
	Ventilation for special equipment	15s	Until prime power restored or orderly shutdown	X	X	Provide purging operation to allow safe shutdown or startup. Reduce hazards to personnel and property. Meet requirements of insurance company. Comply with local, state, and federal codes, standards, and laws.

Power Needed For	Purpose	Maximum Tolerable Power Failure Duration	Recommended Minimum Auxiliary Supply Time	Type of Auxiliary Power		Justification for UPS
				Emergency	Standby	
Space Conditioning (continued)	Non-critical ventilation	1 min	Optional		X	Maintain comfort. Prevent loss of tests
	Control air pollution	1 min	Indefinite until evaluated; compliance or shutdowns are options	X	X	Continue normal operation. Comply with local, state, and federal codes, standards and laws
Data Processing	Power CPU memory tape/disk storage, peripherals	½ cycle	Until prime power restored or orderly shutdown		X	Maintain conditions to prevent malfunctions in data processing system. Prevent damage to equipment and storage media. Continue normal activity.
	Control humidity and temperature	5-15 min (1 min for water-cooled equipment)	Until prime power restored or orderly shutdown		X	Prevent malfunctions in data processing system and damage to equipment Continue normal activity.
Fire Protection	Annunciator alarms	1s	Until prime power restored	X		Comply with local, state, and federal codes, standards, and laws. Lower insurance rates. Minimize damage to life and property.
	Fire Pumps	10s	Until prime power restored		X	Comply local, state, and federal codes, standards, and laws. Lower insurance rates. Minimize damage to life and property.
	Auxiliary lighting	10s	5 min or until prime power restored	X	X	Service fire pump engine should it fail to start. Provide visual guidance for fire-fighting personnel.
	X-ray	Milliseconds to several hours	From no requirement to until prime power restored, as evaluated	X	X	Maintain exposure quality. Ensure availability in emergencies.
Life Support and life safety systems (Medical offices, Hospitals, clinics, etc.)	Light	Milliseconds to several hours	Until prime power restored	X	X	Comply with local, state, and federal codes, standards, and laws. Prevent interruption to operation and operating needs
	Critical-to-life machines and services	½ cycle to 10s	Until prime power restored	X	X	Maintain life. Prevent interruption of treatment or surgery. Continue normal activity.
	Refrigeration	5 min	Until prime power restored		X	Comply with local, state, and federal codes, standards, and laws. Maintain blood, plasma, and related stored material at recommended temperature and in prime condition.
Communication Systems	Teletypewriter	5 min	Until prime power restored		X	Maintain customer services. Maintain production control and warehousing. Continue normal communication to prevent economic loss
	Inner building	10s	Until prime power restored	X		Continue normal activity and control
	Television (CCTV & commercial)	10s	Until prime power restored		X	Continue sales. Meet contractual obligations.. Maintain security. Continue production.
	Radio systems	10s	Until prime power restored	X	X	Continue sales. Meet contractual obligations.. Maintain security. Continue production.
	Intercom systems	10s	Until prime power restored	X	X	Provide evacuation instructions. Direct activities during emergency. Continue normal activities. Maintain security.
	Paging systems	10s	1/2h	X	X	Locate responsible persons concerned with power outage. Provide evacuation instructions. Prevent panic.

Table 3-1. General criteria for determining the purposes of an UPS (continued)
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to assist in determining the purposes of a backup power system, diesel generator, UPS, or combination of diesel may vary. Note that the terms emergency power and standby power are used in the table. An emergency power system can be defined as an independent reserve source of electric energy that, upon failure of the primary source, automatically provides reliable electric power within a specified time to critical devices and equipment which, if they fail to operate satisfactorily, would jeopardize the health and safety of personnel, result in property damage, or cause loss of revenue. A standby power system is an independent reserve source of electric energy that, upon failure or outage of the prime source, provides electric power of acceptable quality so that the user's facility(ies) may continue operation in a satisfactory manner.

c. Determine the power requirements. After determining the specific purpose(s) for an UPS, the next step is to determine the facility power requirements. This task is often laborious but is essential because it sets the stage for the remainder of the selection process. Undefined power requirements, or oversight of any initial conditions, could result in the selection of a system that is not capable of meeting the needs of the facility, costly budget overruns, and delays in completing the project. In addition, there is usually significant growth in the number of UPS loads as a manufacturing plant is developed. This must be accounted for in the sizing of the UPS. Figure 3-3 outlines the process of determining the required power capacity. The first question to answer is how much power is needed. Power requirements can be divided into two categories, critical and non-critical. Critical power can be thought of as power for items such as emergency lighting for evacuation of personnel, security systems, central computing systems, signaling systems, medical equipment, and other functions that could cause loss of productivity, or result in injury or a life threatening situation. Non-critical power is used for functions such as general lighting, escalators, coffee makers, etc. Once the power requirements are defined, the next step is to determine how much (if any) to oversize the unit. Oversizing serves two purposes. First, it provides the capability to efficiently and effectively handle surges in power requirements due to peak demands caused by starting machinery, switching power supplies, etc. Secondly, it provides for growth. Over time, power demands may rise due to the addition of equipment or personnel, increases in productivity, and other reasons. Oversizing the UPS ensures it will have the capacity to handle the increased load without the expense of retrofitting the system, which is more costly in the long run. A general rule of thumb in oversizing is to increase the initial power requirement by 30 percent. If oversizing cannot be justified, the UPS should be selected and the installation designed such that future expansion can be accommodated at the least possible cost.

d. Select the Type of UPS. Selecting a particular type and configuration of an UPS depends on many factors that must be considered and weighted according to a facility's particular requirements. These factors include the purpose of the UPS, the required power, cost, safety, environmental, availability, and maintenance. Note that the selection process (see figure 3-1) is iterative. The type and configuration of the UPS initially selected is based on the purpose and power required. If the selected UPS is not acceptable based on one or more of the remaining factors, another type or configuration must be selected and the evaluation repeated.

e. Determine if the safety of the selected UPS is acceptable. Safety is an overriding concern of any UPS design and installation. Safety is basically governed by the electrical codes and standards as adopted by government and commercial agencies, and good judgment on the part of the design and installation team. In cases where more than one performance or safety design alternative exists, preference should be given to those that have been approved by the governmental authority having jurisdiction. Batteries pose special safety concerns for the facility manager. Safety problems associated with lead-acid batteries include spills of sulfuric acid, potential explosions from the generation of hydrogen and oxygen, and the generation of toxic

gasses such as arsine (AsH₃) and stibine (SbH₃). All of these problems can be satisfactorily handled with the proper safety precautions. National Fire Protection Association (NFPA) 70, National Electrical Code (NEC), provides guidance on battery room ventilation. Wearing face shields and plastic/rubber aprons and gloves when handling acid is recommended to avoid chemical burns from sulfuric acid. Precautions must be routinely practiced to prevent explosions from ignition of the flammable gas mixture of hydrogen and oxygen formed during overcharge of lead-acid cells. The gas mixture is explosive when hydrogen in air exceeds 4 percent by volume. A standard practice is to set warning devices to alarm at 20 to 25 percent of this lower explosive level. Hydrogen accumulation is usually not a problem if good air circulation around a battery is present. If relatively large batteries are confined in a small room, an exhaust fan(s) should be used to constantly vent the room or should start automatically when hydrogen accumulation exceeds 20 percent of the lower explosive limit. Finally, the materials used in the battery container should be fire retardant.

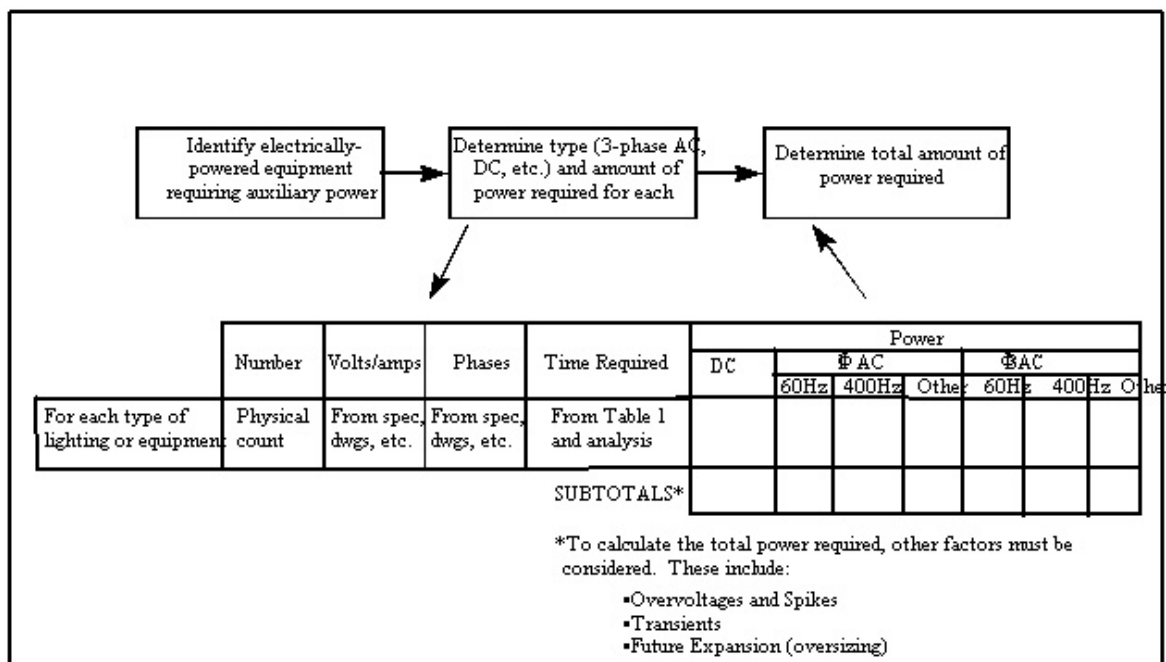


Figure 3-3. Determine the required power is a key step in the UPS selection process

f. *Determine if the availability of the selected UPS is acceptable.* In managing a facility, the availability of equipment and systems is of the utmost concern. Simply stated, availability is the amount of time a piece of equipment is available to perform its function divided by the total time the equipment is needed. It is also defined as “uptime” divided by “total time.” Thus, if an air conditioner is required 12 hours each day, the availability would be 90 percent if it is out of commission an average of 1.2 hours each day. Normally, the required availability for UPS is 98 percent. Availability is a function of reliability and maintainability. The inherent or designed-in availability is usually expressed as follows.

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where: A_i is inherent availability
 MTBF is mean time between failure (a measure of reliability)
 MTTR is mean time to repair (a measure of maintainability)

Reliability is the probability that the item will perform as intended for a specified period of time, under a stated set of conditions. It can be expressed in terms of the number of failures in a given time (the failure rate), or as the time between failures (for repairable items), or time to failure (for “one-shot” or non-repairable items). Maintainability is defined as the relative ease and economy of time and resources with which an item can be retained in, or restored to, a specific condition. This assumes maintenance is performed by personnel having the specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. It can be expressed as the probability that an item can be restored to operational condition in a stated time, the number of repairs that can be made in a specific time (repair rate), or the MTTR. From the equation for A_i , it is obvious that availability can be increased by increasing MTBF or reducing MTTR. For example, assume the MTBF and the MTTR of a single UPS unit are 500 hours and 20 hours, respectively. The inherent availability of a single unit configuration would be:

$$A_i = \frac{500}{500 + 20} = 0.962$$

The inherent availability of a two-unit configuration where only one unit is required would be:

$$A_i = A_1 + A_2 - (A_1 \times A_2) = 0.999$$

The inherent availability of a two-unit configuration where both units are required would be:

$$A_i = A_1 \times A_2 = 0.925$$

The availability could be increased by increasing the reliability or reducing the MTTR. The reliability could be increased by selecting a more reliable unit, derating the unit (i.e., use a unit capable of providing more power than needed - when used, it will be operating below its capacity thereby reducing stresses), or use redundancy (see 3-1f). MTTR could be decreased by selecting an inherently more maintainable system or perhaps by improving diagnostics, training, or procedures.

(1) *UPS reliability.* Reliability is a function of the design of the UPS, the configuration selected, and the parts used. The environment that the UPS is installed in also plays a role in the reliability of the UPS. Environmental factors such as excessive heat, cold, humidity, and/or dust can all have a significant effect on the UPS reliability. Another significant factor in UPS reliability is the configuration. The different UPS configurations were discussed in paragraphs 2-3 and 2-4. Redundancy reduces the overall failure rate of the UPS because one failure does not cause the UPS to fail. The example in figure 3-4 illustrates why this so.

As discussed in paragraph 2-3c, two units may be placed in parallel where each is capable of supplying 100 percent of the load or three units may be placed in parallel where each is capable of carrying 50 percent of the load. The earlier case where one of two units is required is the most reliable. This is shown through the following equations. The reliability where two of three units are required to supply 100 percent of the needed power, is given by the following equation.

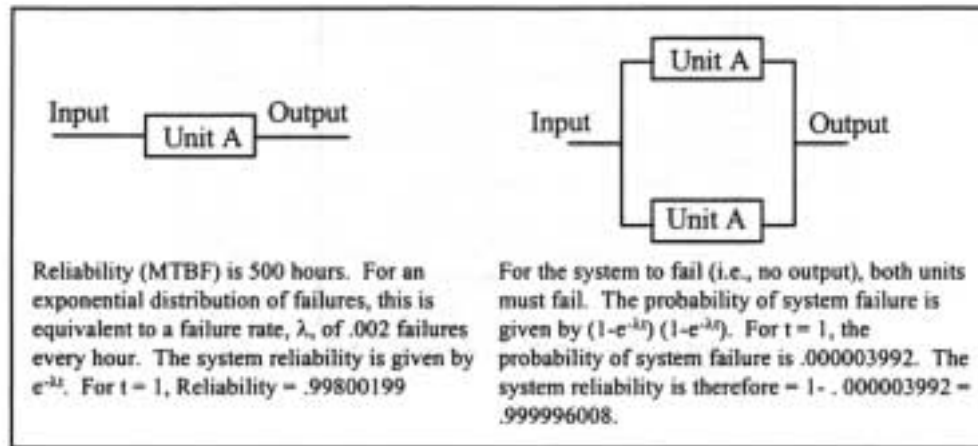


Figure 3-4. Redundancy improves system reliability

$$\text{Reliability} = R(t) = 3e^{-2\lambda t} - 2e^{-3\lambda t}$$

where: λ is the failure rate of each unit and the units fail exponentially
 t is the time over which the system must operate

The reliability where one of two units is needed to supply 100 percent of the power, the reliability is given by the following equation.

$$\text{Reliability} = R(t) = 2e^{-\lambda t} - e^{-2\lambda t}$$

Table 3-2 shows the reliability for various values of t and λ .

Where f/h is failures per hour and h is hours.

Table 3-2. Comparison of reliability of parallel redundant and parallel configurations

λ (f/h)	t (h)	CONFIGURATION	
		Parallel Redundant (1 of 2)	Parallel (2 of 3)
.01	1	0.999901	0.999705
.02	1	0.999608	0.998839
.03	1	0.999127	0.997431
.01	2	0.999608	0.998839
.02	2	0.998463	0.995508
.03	2	0.996609	0.990221
.01	3	0.999127	0.997431
.02	3	0.996609	0.990221
.03	3	0.992592	0.979052
.01	4	0.998463	0.995508
.02	4	0.994089	0.983176
.03	4	0.987213	0.964531
.01	5	0.997621	0.993096
.02	5	0.990944	0.974556
.03	5	0.980598	0.947198

Redundancy is the duplication of elements in a system or installation for the purpose of enhancing the reliability of the system or installation. The two most common redundant designs are the isolated parallel and parallel redundant systems. See figure 3-5.

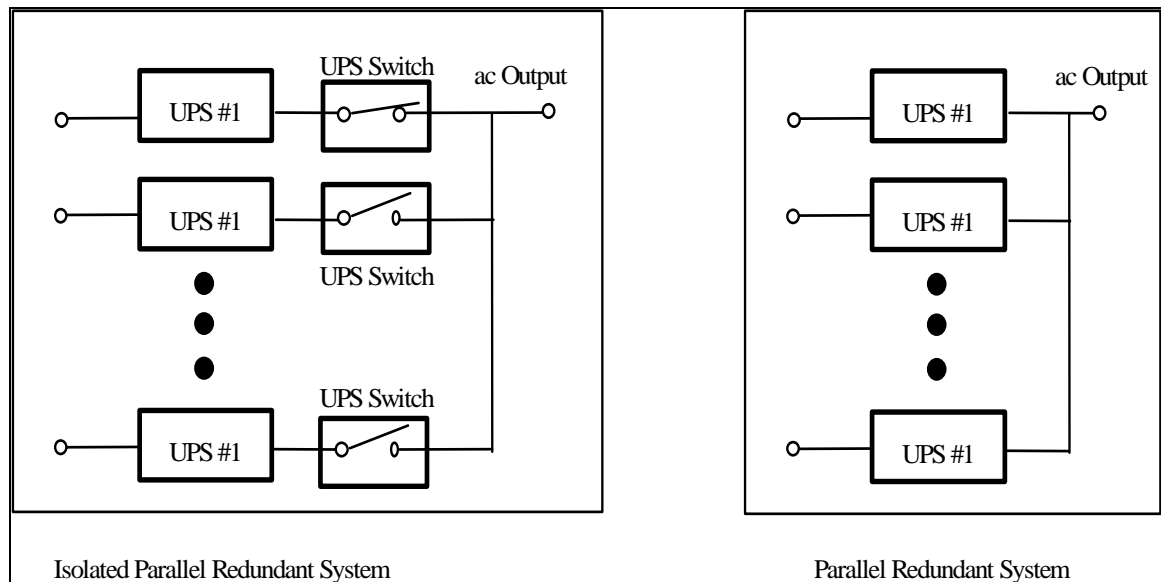


Figure 3-5. Basic redundant UPS designs

Isolated and parallel redundant systems involve paralleling multiple power-conversion modules. The designs are termed redundant because they contain at least one more unit than is required to support the load. The basis for this arrangement is that if one of the power-conversion modules fails or must be taken off line for service, the remaining unit(s) is able to support the load. This approach can provide significant improvement to the systems reliability, but must be designed and installed properly in order to achieve its full potential. Parallel redundant systems can actually be less reliable if the power conversion units are not tolerant of disturbances and overloads on their outputs. Although redundancy improves the system-level reliability, it actually increases the total number of failures that will occur. The reason the number of failures increases is that the number of operating modules, subsystems, or components has increased and nothing has been done to reduce their basic failure rate. The reliability of the UPS is certainly affected by the battery selected. In choosing an UPS, criteria that the buyer might use in evaluating the batteries are shown in table 3-3. Reliability and availability data on UPS components can be obtained by contacting the manufacturer or, if the information is not available, by referencing the Institute of Electrical and Electronics Engineers (IEEE) 500. Due to the nature of their critical loads, C4ISR systems are desired to maintain a reliability level of 99.9999 (commonly known as the six-nine rule). This should be taken into account as one attempts to design or select an UPS system. The selected UPS system, in combination with the overall system, should maintain reliability level of 99.9999 or higher. Therefore, it might be necessary to design and select a system with greater redundancy, in order to achieve the "six-nine" goal.

(2) *Maintainability.* As already shown by the availability equation, reducing the time to restore a system after it has failed is another way to increase availability. Major factors determining the ease and economy with which maintenance can be performed are means for identifying the component(s) that caused the system to fail (i.e., diagnostics), accessibility of components, and skills and resources needed to repair the system (through in-place repair of the failed component(s) or by removing and replacing them).

Table 3-3. Criteria for evaluating UPS battery

CRITERION	FOR RELIABLE PERFORMANCE & LONGER LIFE
The thickness of the positive plate	Thicker is better for durability.
The material used for the battery posts	Copper inserted posts operate more efficiently and cooler, and require less frequent retorquing than do lead posts
How the batteries are tested at the plant	Cells should be tested together
Capacity at which the batteries are shipped from the factory	Anything less than 100% makes it debatable whether 100% can ever be achieved
Tolerance to temperatures above 77°F	The higher, the better
Frequency at which a boost charge is needed	Less frequent is better
Frequency at which testing is required	Less often for short times is better

(a) *Diagnostics.* Identifying what has caused a system failure requires a diagnostics capability. This capability can consist of built-in test, manual troubleshooting procedures, or troubleshooting using external test equipment.

(b) *Accessibility.* Once the component(s) that caused the system to fail are identified through the diagnostic capability available for the system, maintenance personnel must gain access to those components. (Access may also be an issue in performing the troubleshooting of the system failure.) To some extent, the accessibility is determined by the installation as well as the system design. Access to certain areas of an UPS installed in a very limited space may make repair very difficult even though the UPS design is very maintainable.

(c) *Skills and resources.* Even a system that has the most reliable and thorough diagnostics and is designed for total accessibility will not be economical to maintain if highly skilled personnel and extensive and expensive equipment are required. When highly skilled personnel are required, the cost of maintenance increases, obviously. However, the consequences go beyond the cost of actual repairs. Training costs also increase. Ideally, personnel will need only low to moderate skills and a minimum of training (initial and recurring). Special qualifications for UPS maintenance personnel can include fundamentals of electrical and electronic design of UPSs, UPS testing and maintenance practices, specific maintenance training on identical or similar equipment, UPS safety precautions, and facility-specific procedures for operation, surveillance, and maintenance. Economical support is also difficult to achieve if many different pieces of expensive test equipment and tools are needed to support the UPS. Ideally, the only tools required will be common hand tools normally found in a facility maintenance shop and the number and cost of test equipment will be minimal.

g. *Determine if the selected UPS is maintainable.* Maintenance determines much of the operating cost of an UPS. Done correctly, maintenance can ensure that the UPS stays reliable. Poorly done, maintenance can compromise reliability and safety. A system may be inherently maintainable (i.e., good access, good diagnostics, etc.), but other factors can determine whether or not the system can be maintained. These factors include availability of trained personnel, availability of spares and parts, and location of repair facilities for removed components. Availability of personnel is a function of the total number of maintenance personnel, the hours of facility operation (dictates the number of shifts during which maintenance personnel may be required), and training schedules. Availability of spares (to replace removed components) and parts (to repair in-place or removed components) depends on the total number initially procured. Replacement and repair then depends on the rate spares and parts are purchased and the rate at which the spares and parts become obsolete. Location of repair facilities is important because if

they are located a significant distance from the UPS, transportation may increase the time (and the cost) to restore the UPS to operation. In many cases, the facility manager may choose to do only that maintenance performed directly on the UPS (i.e., in-place repair and removal and replacement) with internal resources. All other maintenance (i.e., repair of removed components) would be done by the UPS manufacturer or a third party. Alternatively, the manager may contract out all of the maintenance. This decision should be made primarily on the basis of cost and availability. The cost of hiring and training personnel should be compared to that of contracting out all or some of the maintenance. The expected number of repairs should be considered. A study of high failure rate components and the stock levels needed to minimize down time is also important. Another party might be able to maintain the required stock levels at a lower cost and might be able to make repairs in a shorter time. On the other hand, many contractors require time (typically 24 hours) to respond to a problem. This additional time may result in large losses of revenue. Even if internal repair is more expensive, the added cost may be more than offset by the savings in revenue.

h. Determine if the selected UPS is affordable. Although discussed as the last step in the selection process, affordability is often a limiting factor in the selection of an UPS. It is placed last because the pricing of the UPS can only be done when the type, configuration, and sizing are known. These parameters cannot be known until the steps in paragraph 3-1 have been completed. When considering the cost of an UPS (or any product, for that matter), it is best to consider the total cost, or *life cycle cost*, that will be incurred. (See figure 3-6 that describes the process for determining affordability.) For an UPS, the total cost includes the purchase price, installation cost, operating and support costs, and disposal costs. The acquisition and installation of the

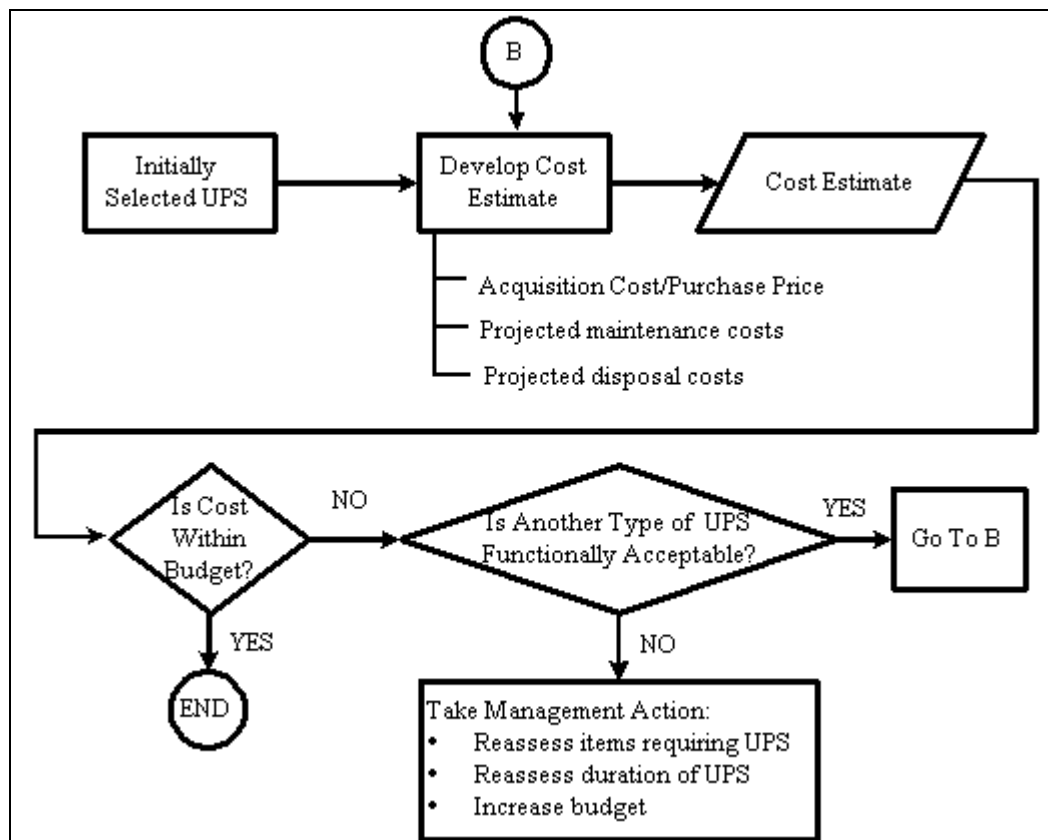


Figure 3-6. Determining affordability requires that all costs be considered

UPS typically constitute the greatest portion of the life cycle cost. A static UPS will cost between \$100 and \$250,000 while the cost of a rotary ranges between \$5000 and \$1,000,000 for single units. The cost of any needed auxiliary equipment must also be considered. At a minimum, a manual bypass switch is required to disengage the UPS from the input power and load during maintenance or repair. These switches are typically integrated into a static UPS but are stand-alone items with rotaries. In the latter case, the switches require additional cabling and support hardware. More sophisticated systems having automatic monitoring, switching, and control functions requiring additional components, adding to the complexity and cost of the system(s). As part of the installation costs, the costs associated with needed facility modifications should also be considered. If the UPS is operated under adverse conditions, availability will suffer. Specific precautions must be taken for dirty, hot, cold, corrosive, explosive, tropical and other adverse conditions. Additional air conditioning might be required for the UPS (or for the facility due to heat loads from the UPS). Rotary units may require additional or special ventilation equipment to purge toxic fumes from working areas. Floor units (usually static UPS for computer system backup) may require strengthening of the floor to support their weight. Large UPSs may require the construction of a separate building to house the unit. A rotary UPS or engine generator used in a cold climate will probably require thermostatically controlled lubricating oil, coolant heaters, and radiator louvers. All equipment manufacturers specify the temperature extremes, humidity, and other conditions for which the UPS was designed. Operating and support costs of the UPS are usually secondary to the costs of purchasing and installation. However, they can be substantial and should be included as a factor in the final selection. Operating and support costs include cost of fuel, maintenance, replacement parts, and taxes. Finally, when an UPS reaches the end of its life, disposal costs will be incurred. Disposal may simply consist of dismantling the UPS and selling the parts to a recycling company or dumping it at an approved refuse site. For UPSs containing dangerous or environmentally unsafe chemicals or materials, disposal is much more complicated and expensive. For example, disposal of lead-acid batteries must be performed according to all federal, state, and local regulations. Lead-acid batteries should be reclaimed to avoid the regulatory requirements for hazardous waste treatment and disposal facilities. Reclamation may be included as part of a procurement contract for replacement batteries or contracts may be placed with a permitted reclaiming facility. In disposing of spent batteries, the facility manager must ensure that batteries meet all radioactive contamination requirements for uncontrolled release. A variety of UPS types and configurations can be selected. The costs can vary widely depending on the specific type and configuration selected. It is impractical to provide an all-inclusive cost comparison of all possible combinations of types and configurations.

3-2. Static UPS system ratings and size selection

Presently, there are no standard ratings and performance characteristics for static UPS systems. However, the typical performance specifications from various manufacturers are indicated in tables 3-4, 3-5, and 3-6. The performance specifications are normally based on operating the static UPS system under typical environmental conditions as shown in table 3-7. These ratings only provide a general listing of typical ratings. The manufacturer's ratings shall be used to determine if the UPS will perform in the specified environment. It may be necessary to derate the equipment where the manufacturer's performance specifications are exceeded.

a. Determining static UPS system rating. In order to properly size and select a static UPS system, the load kVA, load power factor, inrush kVA or current, load voltage, number of phases and frequency, and required battery protection time should be determined for the load to be served.

(1) *Determining load kVA.* In existing installations, the load kVA should be determined by measuring the current with all equipment operating. In three-phase installations, the load current should be measured at each phase. The load kVA can then be estimated as follows.

Table 3-4. Typical rectifier/charger ratings

a. Input Voltage	208, 220, 240, 380, 415, or 480 V, $\pm 10\%$, 3 phase / 120/220 V, $\pm 10\%$, 1phase
Frequency	50 or 60 Hz. $\pm 0.5\%$
Power Factor (typical)	0.8
b. Output Nominal Voltage	110 VDC, 220 VDC nominal 130VDC, 260 VDC nominal $\pm 5\%$ adjustment
Equalize Voltage	140 VDC, 280 VDC $\pm 5\%$ adjustment
Ripple Voltage	<2% RMS with batteries
Equalize Timer	1-100 hours, manual start, auto-reset
Capacity	Sized to recharge the battery in 8 to 10 hours

Table 3-5. Typical inverter ratings

a. Input Voltage (range)	120, 220 V $\pm 20\%$
b. Output Voltage	120 V, single phase 280 V or 480 V, 3 phase, 3 or 4 wire
Voltage Regulation	$\pm 2\%$ for balanced load $\pm 3\%$ for 100% unbalanced loads (3 phase only)
Sync range	± 0.5 Hz
Load Power factor	0.8 to 1.0
Transient Recovery	$\pm 3\%$ within 10 milliseconds $\pm 1\%$ within 30 milliseconds
Harmonic Distortion	3% maximum single harmonic 5% THD maximum up to crest factor 2 3% THD maximum for linear loads
Frequency	50 or 60 Hz $\pm 0.1\%$
Overload Capacity	500% for 1 cycle, 120% continuous
Crest factor	3:1 at full load

Table 3-6. Typical static switch ratings

Transfer Time	0 s (Make-before-break)
Overcurrent Transfer	120% of rated full load current
Overload Capacity	1000% for 1 cycle

Table 3-7. Typical environmental ratings

ambient temperature range	0° to 40°C
relative humidity range	0 to 95% non-condensing
operating Altitude	0 to 1200 meters
audible noise	<67 dB(A) at 1.5 meters

Single-phase loads

$$kVA = \frac{VI}{1000}$$

where: V is the system voltage in volts

I is the measured current in amperes

Three-phase loads

$$kVA = 1.73 \frac{VI}{1000}$$

where: V is the phase-to-phase voltage in volts

I is the highest measured phase current in amperes

In cases where the load current cannot be measured or when the installation is in the planning stage, the load kVA should be calculated. Calculating the kVA requires obtaining the individual load kVAs from equipment manufacturers' data. The total load kVA is then obtained by vectorially adding the individual load kVAs. However, when an individual load power factor is not available, it can be estimated from the data in table 3-8. Also, an approximate but conservative estimate of the load kVA may be obtained by arithmetically adding the individual load kVAs.

Table 3-8. Typical load power factors and inrush requirements

Type of Load	Power Factor	Inrush %	Duration
Induction motor or MG set	0.75	500-800	1-30 sec.
Computer central processor unit	0.9-0.85	600-1000	2-6 cycles
Computer peripherals	0.8	500-800	1-30 sec.
Process instruments & controls	0.85	300-500	2-6 cycles
Fluorescent lights (corrected type)	0.95	300-600	1 cycle
Incandescent lights	1.0	600-1500	2-6 cycles
Regulated DC power supply (or battery charger)	0.6-0.8	600-1000	2-6 cycles
Unregulated DC power supply	0.9	600-1000	2-6 cycles
Transformer	Same as load	1000	1 cycle
Magnetic line regulators (auto-transformer)	0.6-0.8	200-300	1 cycle
Ferroresonant type line regulators (CVT)	0.5 lead to 0.5 lag	600-1000	1-3 cycles
Solenoids, Relays and Contactors	0.5	1000	2-3 cycles

(2) *Determining load power factor.* In existing installations, the load power factor should be determined by actual measurements using a power factor meter. In cases where actual measurements cannot be taken or when the installation is in the planning stage, the load power factors should be calculated. To calculate the load power factor, the kVA and power factor of the individual loads should be obtained from the equipment manufacturers' data. When a load power factor is not available, it can be estimated from the data in table 3-8. The total load power factor can then be calculated. Estimating the load power factor is necessary since the kVA rating and performance parameters of most static UPS system designs are guaranteed only at a power factor

range of 0.8 lagging to unity. The static UPS system kVA capacity and performance parameters are affected at other power factors.

(3) *Determining load inrush kVA.* Determination of the load inrush kVA is particularly important for static UPS configurations without a static transfer switch and bypass capability. In these configurations, if the load inrush kVA requirements exceed the inverter capability, the inverter will reach the “current limit” mode causing the output voltage to drop. In configurations with a static transfer switch and bypass capability, determining the load inrush current requirements is required for proper selection of overcurrent protective devices for the transfer switch and coordination with other overcurrent protective devices. The load inrush kVA or current in existing installations should be determined by actual measurement using a high speed storage oscilloscope or oscillograph. Since all loads are not normally started simultaneously, the inrush kVA or current requirements should be determined by energizing the load with the highest inrush kVA while all other loads are connected. In cases where measurements cannot be taken or when the installation is in the planning stage, the load inrush requirements should be calculated. Data on individual load inrush kVA and duration should be obtained from equipment manufacturers or estimated from the data in table 3-8. The maximum inrush current and effective inrush current can be calculated.

(4) *Load voltage, number of phases, and frequency.* The load voltage and frequency requirements determine the UPS system output voltage and frequency. Three-phase loads require a system with three-phase output regardless of the kVA rating required. However, when all loads are single-phase, a system with single-phase output is preferable up to a rating of 75 kVA. When the single-phase loads are higher than 75 kVA, a system with three-phase output is normally used. In such a case, the loads should be distributed among the three phases to minimize the phase unbalance effects on the inverter.

(5) *Battery protection time.* Battery protection time depends on the load type and functions. Generally, a battery with a minimum protection time of one minute is necessary for the initial operation of the inverter without support from the power supply source, i.e., during the walk-in time. There is no upper limit for the protection time. However, other considerations may limit the length of battery protection time. Examples are the loss of the environmental control support, which could limit the length of a computer operation time with power loss to 5, 10, or 15 minutes. In such a case, there is no need to select a battery protection time which can extend computer operating time beyond the time for which a computer system can operate before it must shutdown due to overheating.

b. *Battery sizing.* In order to properly size the battery, required discharge rate in kilowatt (kW)/cell, required protection time, end of discharge voltage, and ambient temperature should be determined.

(1) *Discharge rate.* For an UPS system battery, the discharge rate should correspond to the highest inverter input power required to produce rated output at minimum input dc voltage. The end of discharge voltage should be equal to or higher than the minimum dc input voltage required by the inverter to maintain rated performance. The minimum dc voltage required by the inverter is normally published by the manufacturer. The maximum dc power required by the inverter can be obtained from the manufacturer or can be calculated. In addition, it is recommended to include a margin of 30 percent for the required capacity to account for load growth and battery aging.

(2) *Lifetime.* The expected lifetime of batteries on UPS duty is usually stated in terms of years of service on continuous charge to an end of life defined as the failure to be able to deliver a certain percentage of rated capacity. Initial capacity (unless specified as 100 percent capacity) is usually in the range of 90 to 95 percent of rated capacity. This will rise to 100 percent capacity in normal service after several charge-discharge cycles. IEEE 450 recommends that a battery be replaced when its actual capacity drops to 80 percent of rated capacity; however, some manufacturers rate "end-of-life" at 50 percent of rated capacity. Obviously, the user needs to check the initial capacity rating, the service life period, and the aging characteristics given in the battery guarantee so as not to be unpleasantly surprised.

(3) *End of discharge voltage.* UPS batteries are not sized on so many ampere-hours of capacity for an 8-hour period. Battery voltage is not constant, so if the load requires a constant power output, which most UPS applications do, the current must increase as the voltage decreases. Consequently, the battery is sized to supply a specific kW rate (usually the maximum inverter kW requirement without recharging) for a specific period of time (usually 5 to 15 minutes) to a minimum specific end voltage and, for lead-acid types, at a maximum specific gravity (measured at 77°F).

(a) *Lead-acid cells.* A nominal system design may utilize minimum end voltage of 1.67 to 1.75 volts per cell and a maximum specific gravity of 1.215 at 77°F. The actual end voltage should be the voltage which the UPS manufacturer, battery manufacturer, or the system design requires, whichever is higher. In some cases, designs provide higher end voltages to meet design concerns. A higher specific gravity may result in a battery installation needing less space, but results in shorter life spans and higher cell losses and float voltages. The lower end voltage that manufacturers recommend may cause the UPS to go to static bypass or, by overstressing battery plates, shorten the life of the battery.

(b) *Nickel-cadmium (ni-cad) cells.* A nominal system design for ni-cad units will be to a minimum end voltage of 1.14 volts at 77°F with the actual end voltage to meet both manufacturers' and system design requirements. The specific gravity of a new cell will vary between 1.160 and 1.190 at 77°F, depending upon the manufacturer. Lower specific gravities are generally used in cells with larger electrolyte reserves. Higher specific gravities are typically used for low-temperature applications. The specific gravity will decrease slowly over the years because of evaporation and other effects, even though the surface of the electrolyte is probably covered with a protective layer of oil. Renewal will be necessary if the specific gravity decreases to 1.130 to 1.160, depending upon the manufacturer's instructions.

(c) *Temperature correction.* Ratings are at 77°F (25°C). Therefore, to determine specific gravity, which is temperature sensitive, a temperature correction factor must be applied. For both lead-acid and ni-cad batteries, add one point (.001) to the hydrometer reading for every 3°F above 77°F and subtract one point for every 3°F below 77°F.

(4) *Ambient temperature.* The usual controlled environment provided for batteries should eliminate temperature correction while a 100 percent UPS inverter capacity normally allows an adequate kW design margin. The life of a battery in comparison with an UPS system (which may be outdated and replaced in much less time) may mean that the aging factor is not of such great importance.

c. *Computation sheets.* The typical computation sheet in appendix B is intended for calculating the kVA rating and inrush capability of a single-phase static UPS system with static bypass switch. The methodology used in this computation sheet can be used to develop

computation sheets for other system configurations. For example, for a three-phase system, the step-by-step procedure should be followed for each phase. The system kVA rating should be three times the largest single-phase kVA obtained. For systems without a static transfer switch, the maximum inrush current obtained should be below the value at which the system reaches the current limit mode.

d. Static UPS system selection criteria. Selection of a static UPS system should be in accordance with certain criteria. The system output voltage and frequency shall be as required by the loads. The output shall be three-phase when any of the loads is a three-phase load, otherwise a single-phase system should be used for ratings up to 75 kVA. The system output voltage and frequency regulation and transient response shall meet the requirements of the most power-sensitive load(s). The system rated kVA at the specific site shall be equal to the load kVA plus a 25 to 30 percent margin. The system shall be capable of supplying the load inrush demand without reaching the current limit mode. The battery protection time shall not be less than one minute and shall not exceed the maximum time the load can be operated with the loss of the environmental support equipment as specified by the equipment manufacturer (normally in the range of 1 to 15 minutes).

3-3. Rotary UPS system ratings and size selection

Similar to static UPS systems, there are no standard ratings and performance characteristics for rotary UPS systems. Also, since the use of rotary UPS systems is much less common, the number of manufacturers offering rotary UPS systems is limited. Each rotary UPS system configuration may have unique performance characteristics. Performance characteristics of typical configurations are shown in table 3-9.

Table 3-9. Updated typical rotary UPS ratings

	Induction Motor Generator/ Kinetic Battery	Asynchronous motor generator/ induction coupling
Protection Time	12 s	2 s
Voltage Regulation	±1%	±1%
Voltage Drop or Rise for 50% Load Step	±3% @ 1.0 pf	±6%
Change from Full Load	±4% @ 0.8 pf	
Voltage Transient Recovery Time	150 ms to ±2%	250 ms
Frequency Regulation	±0.5 Hz	±0.5 Hz
Frequency Transient Recovery Time	0.5 s	0.5 s
Phase Angles, Unbalanced Loads up to 20 Percent	120° ± 1°	120° ± 1°
Harmonic Voltage	1.5 % THD (Ph-Ph) 2.5 % THD (Ph-Ph)	4% max.

a. Determining rotary UPS system rating. In order to properly size and select a rotary UPS system, the load kVA, load power factor, inrush kVA or current, load voltage, number of phases and frequency, required battery protection time (if battery supported UPS), maximum permissible frequency deviation (if inertia-driven UPS), and required ride-through time (if inertia ride-through UPS) should be determined. This information can be determined in the same manner as described in paragraph 3-2 for determining a static UPS system rating. The maximum permissible frequency deviation and required ride-through time is required for sizing the flywheel inertia as will be described in the following paragraph. The maximum permissible frequency deviation should be the maximum deviation tolerated by the most sensitive load. The required ride-through time depends

largely on the nature of the power supply source. It should be longer than the longest momentary interruption experienced or expected at the particular installation. The longest momentary interruption time is usually the duration of reclosing operations on the power supply distribution feeders. In addition, the nature and percentage of non-linear loads should be determined. This is necessary to insure that the system's level of voltage distortion when supplying such loads is acceptable.

b. Motor and generator ratings. Motor and generator ratings and performance characteristics are standardized by the National Electrical Manufacturers Association (NEMA) in ANSI/NEMA Publication MG-1, 1978.

(1) *Synchronous motors.* The NEMA rating structure of continuous duty synchronous motors is based on horsepower output, maximum ambient temperature for which motor is designed, speed at full load, frequency, number of phases, voltage, full load current, field current, excitation voltage, power factor, and locked rotor (starting) kVA.

(2) *Induction motors.* The NEMA rating structure of continuous duty induction motors is based on horsepower output, maximum ambient temperature for which motor is designed, speed at full load, frequency, number of phases, voltage, full load current, and lock rotor (starting) kVA.

(3) *DC motors.* The NEMA rating structure of continuous duty dc motors is based on horsepower output at base speed, maximum ambient temperature for which the motor is designed, base speed at rated load, armature voltage, field voltage, armature load current at base speed, and winding type - shunt, series, or compound.

(4) *Synchronous generators.* The NEMA rating structure at synchronous generators is based on kVA output, output power (kW), power factor, maximum ambient temperature for which the generator is designed, speed, voltage, full load current, number of phases, frequency, excitation current, and excitation voltage.

c. Flywheel sizing. The flywheel inertia is selected such that the stored energy is sufficient to supply the generator while operating at rated power for a duration not exceeding 0.5 second while keeping the speed from falling to maintain the frequency drop to a maximum of 0.5 Hz. The flywheel inertia plus the inertia of the coupled motor(s) and generator make up the total inertia of a rotary UPS system. The flywheel inertia is usually more than 95 percent of the total inertia and the motor's and generator's inertias can be neglected. The required flywheel inertia (WK^2) can be calculated as follows.

$$WK^2 = H \frac{kW \times 10^6}{(0.231)(n)} (lb - ft^2)$$

where: kW = generator rated power (kW)

n = generator rated rotational speed (r/min)

The inertia constant (H) is determined based on the required ride-through time and minimum frequency as follows.

$$H = t / \left[1 - \left(\frac{F_{\min}}{f_r} \right)^2 \right]$$

where: t = required ride-through time (s)

F_{\min} = minimum frequency required at the end of the ride-through time (Hz)

f_r = generator rated frequency (Hz)

Theoretically, a flywheel can be selected to provide any ride-through time. However, practical and economical considerations limit the ride-through time to around 0.5 second. High flywheel inertia causes a long motor starting time. During the starting time, the motor's high starting current can cause unacceptable or excessive motor heating. Also, due to the flywheel's heavy weight and the long starting time, special bearings and lubrication methods may be required.

d. Rotary UPS system selection criteria. Selection of a rotary UPS system should be in accordance with certain criteria. The system output voltage and frequency shall be as required by the loads. The output should preferably be three-phase except for small systems (5 kVA and smaller) where single-phase systems may be used. The system output voltage and frequency regulation and transient response shall meet the requirements of the most power sensitive load(s). The system rated kVA at the specific site shall be equal to the load kVA plus a 10 to 15 percent margin. The system shall be capable of supplying the load inrush demand without voltage and frequency deviations beyond the required tolerances. The inertia-driven ride-through configuration should be considered at sites where the power distribution system has a high reliability and long duration interruptions are not frequently experienced. The battery supported inertia configuration should be considered at sites with frequent long duration power interruptions. The battery protection time shall not be less than one minute and shall not exceed the maximum time the load can be operated with the loss of the environmental support equipment.